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Utilization of Lightweight Materials Made From Coal Gasification Slags

Quarterly Report

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For
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TABLE OF CONTENTS

1.0 PROJECT OBJECTIVES, SCOPE AND DESCRIPTION OF TASKS

1.1 Introduction

Integrated-gasification combined-cycle (IGCC) technology is an emerging technology that utilizes coal for power generation and production of chemical feedstocks. However, the process generates large amounts of solid waste, consisting of vitrified ash (slag) and some unconverted carbon. In previous projects, Praxis investigated the utilization of "as-generated" slags for a wide variety of applications in road construction, cement and concrete production, agricultural applications, and as a landfill material. From these studies, we found that it would be extremely difficult for "as-generated" slag to find large-scale acceptance in the marketplace even at no cost because the materials it could replace were abundantly available at very low cost. It was further determined that the unconverted carbon, or char, in the slag is detrimental to its utilization as sand or fine aggregate. It became apparent that a more promising approach would be to develop a variety of value-added products from slag that meet specific industry requirements. This approach was made feasible by the discovery that slag undergoes expansion and forms a lightweight material when subjected to controlled heating in a kiln at temperatures between 1400 and 1700°F. These results indicated the potential for using expanded slag as a substitute for conventional lightweight aggregates (LWA). The technology to produce lightweight and ultra-lightweight aggregates (ULWA) from slag was subsequently developed by Praxis with funding from the Electric Power Research Institute (EPRI), Illinois Clean Coal Institute (ICCI), and internal resources.

The major objectives of the subject project are to demonstrate the technical and economic viability of commercial production of LWA and ULWA from slag and to test the suitability of these aggregates for various applications. The project goals are to be accomplished in two phases: Phase I, comprising the production of LWA and ULWA from slag at the large pilot-scale, and Phase II, which involves commercial evaluation of these aggregates in a number of applications. Phase I was due to end on 14 December 1995 but has been extended to 14 June 1996 due to the unexpectedly long time it took for collection of slag samples. The scheduled completion date for Phase II has therefore been extended to 14 September 1997.

Primary funding for the project is provided by DOE's Morgantown Energy Technology center (METC) with significant cost sharing by Electric Power Research Institute (EPRI) and Illinois Clean Coal Institute (ICCI).

1.2 Scope of Work

The project scope consists of collecting a 20-ton sample of slag (primary slag), processing it for char removal, and pyroprocessing it to produce expanded slag aggregates of various size gradations and unit weights, ranging from 12 to 50 lb/ft^3. A second smaller slag sample will be used for confirmatory testing. The expanded slag aggregates will then be tested for their suitability in manufacturing precast concrete products (e.g., masonry blocks and roof tiles) and insulating concrete, first at the laboratory scale and subsequently in commercial manufacturing plants. These products will be evaluated using ASTM and industry test methods. Technical data generated during production and testing of the products will be used to assess the overall technical viability of expanded slag production.

In addition, a market assessment will be made based on an evaluation of both the expanded slag aggregates and the final products, and market prices for these products will be established in order to assess the economic viability of these utilization technologies. Relevant cost data for physical processing and pyroprocessing of slag to produce expanded slag aggregates will be gathered for comparison with (i) the management and disposal costs for slag or similar wastes and (ii) production costs for conventional materials which the slag aggregates would replace. This will form the basis for an overall economic evaluation of expanded slag utilization technologies.

1.3 Task Description

A summary of the tasks to be performed in Phase I is given below:

Task 1.1 **Laboratory and Economic Analysis Plan Development**: Development of a detailed work plan for Phase I and an outline of the Phase II work.

Task 1.2 **Production of Lightweight Aggregates from Slag**: Selection and procurement of project slag samples, slag preparation including screening and char removal, and slag expansion in a direct-fired kiln and fluid bed expander. Preliminary laboratory-scale studies will be conducted before bulk samples of expanded slag are collected for processing. The char recovered from the slag preparation operation will be evaluated for use as a kiln fuel and gasifier feed. Environmental data will also be collected during preparation and expansion of slag.

Task 1.3 **Data Analysis of Slag Preparation and Expansion**: Analysis and interpretation of project data, including development of material and energy balances for slag processing and product evaluation.

Task 1.4 **Economic Analysis of Expanded Slag Production**: Economic analysis of the utilization of expanded slag by determining production costs for slag-based LWAs and ULWAs. An estimated market value will be established for the various expanded slag products. Expanded slag production costs will be compared with the costs of disposal and management of slag as a solid waste.

Task 1.5 **Topical and Other Reports**: Preparation and delivery of topical, financial status, and technical progress reports in accordance with the Statement of Work.

The Phase II effort will focus on field studies conducted on expanded slag aggregates to test their performance as substitutes for conventional materials in various applications, including masonry blocks, roof tiles, insulating concrete, and insulation fill. Mix designs will be formulated and tested by refining the material proportions used in previous work. Commercial manufacturing practices, standards, and equipment will be used for this work. New applications may also be identified during the course of this work. The economic analyses conducted in Phase I will be further refined in Phase II using the new data.

1.4 Scope of this Document

This is the seventh quarterly report and summarizes the work undertaken during the performance period between 1 March 1996 and 31 May 1996.

2.0 SUMMARY OF WORK DONE DURING THIS REPORTING PERIOD

2.1 Summary of Major Accomplishments

The following was accomplished during the current reporting period:

1. Laboratory-scale applications-oriented testing of SLA as a substitute for LWA and ULWA continued in the current reporting period. This work involves testing the SLA products prepared during pilot-scale operations in the following applications:

   - Structural concrete (three SLA products)
   - Lightweight concrete masonry unit (lightweight blocks, 2-3 blends)
   - Insulating concrete
   - Lightweight roof tile aggregate (three SLA products)
   - Loose fill insulation
   - Horticultural application.

2. The draft Phase I Final Report was prepared and submitted to METC. This will be revised based on the comments of the COR and resubmitted in final form by the end of June 1996.

3. Work was initiated to prepare and submit all reports in Adobe Acrobat Portable Document Format (PDF) as requested by METC. This format will be implemented for Phase II Reports starting with Quarterly Report No. 8.

4. An application for continuation of the project to Phase II was submitted to METC.

2.2 Chronological Listing of Significant Events in This Quarter

The following significant events occurred during the current reporting period:

Date	Description
4/1/96	Testing of SLA in roof tile application initiated
4/30/96	Application for continuation of funding to Phase II submitted
5/17/96	Testing of SLA in insulating concrete application initiated
5/31/96	Phase I Final Report (draft) dispatched to METC

3.0 TO DATE ACCOMPLISHMENTS

This section summarizes the work completed to date in the first six quarters of the project:

Date	Accomplishments
10/24/1994	"Draft Laboratory and Economic Analysis Plan" prepared and submitted
11/07/1994	Advance sample of primary project slag collected for testing for char removal
11/18/94	Slag processing for char removal completed successfully on the advance sample and prepared slag sent to Fuller and Silbrico for expansion testing
12/02/94	Final "Laboratory and Economic Analysis Plan" prepared and submitted
12/14/94	Testing of advance slag sample at Fuller and Silbrico indicates that it has excellent expansion properties
02/15/94	Evaluation of blendability of slag fines with an expansible clay initiated at Fuller
03/05/95	Decision made regarding primary and secondary project slag samples
04/15/95	Laboratory extrusion testing of the advance sample using an expansive clay binder completed at Fuller
05/21/95	Primary slag sample received at Penn State for preparation
05/30/95	Characterization of primary slag using samples from two drums completed
06/01/95	Pilot unit for char removal set up
06/21/95	Second slag sample tested and evaluated for expansion characteristics
06/30/95	Char removal operational problems solved and continuous slag processing started
08/20/95	Primary slag sample processing for char removal completed
08/31/95	Slag screening of primary slag at 10 mesh and 50 mesh started
9/10/95	Laboratory studies of slag expansion on the two slags completed
9/20/95	Laboratory testing of pelletized slag/clay blends started
10/15/95	1-ft and 3-ft diameter kilns commissioned for pilot testing
11/15/95	Pilot testing of Slag I in 3-ft dia. direct-fired kiln completed
11/16/95	Pilot testing of pelletized Slag I in 1-ft dia. direct-fired kiln completed
11/17/95	Pilot testing of Slag II in 1-ft dia. direct-fired kiln completed
12/10/95	Test planning for slag lightweight aggregate (SLA) laboratory evaluation continued
12/12/95	SLA product characterization initiated
1/20/96	Laboratories for testing of SLA products identified
2/16/96	Test plan for second batch of fluid bed expander testing at Fuller completed
2/21/96	SLA product samples prepared for laboratory evaluation
4/1/96	Testing of SLA I roof tile application initiated
4/30/96	Application for continuation of the project to Phase II submitted
5/17/96	Testing of SLA in insulating concrete application initiated
5/31/96	Phase I Final Report (draft) submitted to METC

4.0 TECHNICAL PROGRESS REPORT

The major accomplishments during this reporting period were in the following areas:

- Laboratory evaluation of slag-based lightweight aggregates for lightweight roof tile, lightweight concrete, and insulating concrete production

- Preparation of the Phase I Final Report (Topical Report No. 1)

4.1 Laboratory Evaluation of SLA for Roof Tile Application

The objective of this test program is to develop mix designs to produce sand and SLA-based cement concretes with compressive strengths in the 2500-4000 psi range and unit weights in the 115-105 lb/ft^3 range by varying the proportion of cement relative to the SLA. The SLA samples that will be tested are identified in Table 1. In addition, a control sample of commercially available structural aggregates will be tested. As indicated in the table, 3/4" coarse SLA aggregates will be tested at three strength levels (complete matrix) whereas the other samples will be tested at only one level of cement.

Table 1. Tentative Cement Levels to Test SLA as Structural Aggregate

SLA Products Tested	Tentative Cement Level, $Sacks/Yard^3$
(i) 3/4" SLA (50/50 slag-clay pellets) as 3/4" coarse LWA	5½, 6½, and 7½
(ii) 1/4" x 50M SLA crushed as 3/8" combined LWA	One level of cement
(iii) Expanded 3/4" clay pellets	One level of cement

Exploratory tests were conducted to establish appropriate sand, water, and cement requirements in order to achieve the target mechanical properties. The strength and unit weight of the resulting concrete specimens were measured and, based on these results, final mix designs are being developed for the various expanded slags.

4.2 Laboratory Evaluation of SLA for Roof Tile Application

Three different kinds of aggregates were tested for the lightweight roof tile application using ASTM C 109 specifications for testing mortars. The three aggregates were 100% expanded slag, 50/50 expanded slag/clay, and a 100% clay control sample provided by a commercial roof tile manufacturer. The 100% slag aggregates and the 50/50 slag/clay aggregates were sized to match the size distribution of the clay aggregates used by the roof tile manufacturer. Typically, a roof tile mix uses a cement-to-aggregate ratio of 1:2.5, along with various additives such as accelerators and superplasticizers. In order to mimic products available in the market for purposes of comparison, two different kinds of accelerators and a common commercial superplasticizer were evaluated. The accelerators tested were calcium chloride dihydrate ($CaCl_2 \bullet 2H_2O$) and sodium silicate.

During the experimental stage, all the aggregates were used in their saturated surface dry (SSD) condition as defined by ASTM. The moisture content of the three aggregates in their SSD condition was measured and recorded.

Because the specific mix formulations used by roof tile manufacturers are considered proprietary information, many experiments were conducted with varying amounts of accelerator, superplasticizer, and water-to-cement ratios with the goal of obtaining the highest 7-day compressive strength without using excessive additives. Three 2" x 2" x 2" mortar cubes were cast and cured in a wet box (relative humidity of ~70%) for 2 hours and then steam-cured at ~60°C for 4 hours. The cubes were demolded and returned to the wet box for further curing to 7 days. The cubes were then weighed and broken in compression. A summary of the formulations and 7-day compressive strengths is presented in Table 2.

Table 2. Formulations and 7-Day Compressive Strength of Roof Tile Samples

Aggregate Type	$CaCl_2 \bullet H_2O$ (wt% of cement)	Super-plasticizer (wt% of cement)	Mortar Unit Wt (lb/ft^3)	Water/ Cement Ratio	SSD (%)	7-day Compressive Strength (psi)
Expanded slag	2	5.5	90.5	0.26	18	668
Expanded slag	2	5	92.3	0.29	18	934
Expanded slag	2	2	92.6	0.32	18.5	2303
Expanded slag	2	2	93.3	0.35	18.5	2806
Expanded slag	2	2	96.8	0.38	17.4	2028
Expanded slag	2	2	97.1	0.41	17.4	1743
Expanded slag	2	1.5	98.3	0.38	17.4	2650
Expanded slag*	2	1.5	101.7	0.38	18	2432
Control**	2	2	109.3	0.38	17	2011
Control**	2	2	108.7	0.41	17	2802
Control**	2	2	105.3	0.45	17	3390
Control**	2	2	105.2	0.50	17	3106
50/50 slag/clay	2	1.5	105.2	0.35	26	2303
50/50 slag/clay	2	1.5	101.9	0.38	26	1917
50/50 slag/clay	2	1.5	101.8	0.41	26	1736

* 1% sodium silicate was added for this test.
** Control aggregate was produced at a commercial kiln and provided by a roof tile manufacturer.

The highest 7-day compressive strength for the expanded slag specimens was 2806 psi, which is 83% of the highest strength obtained for the expanded clay samples. Visual inspection of the crushed slag-based cubes revealed that the cement/aggregate interface was sound and that failure was chiefly due aggregate breakage. This was confirmed by the specimens made from 50/50 slag/clay. The unit weight of the 100% expanded slag specimens ranged between 91 and 98 lb/ft^3, that of the 50/50 specimens between 102 and 105 lb/ft^3, and that of the 100% clay control specimens between 91 and 101 lb/ft^3.

These experiments also showed that the mechanical behavior of the samples is greatly affected by the water/cement ratio but not by the type of accelerators used. Typically, in cement systems, lowering the water/cement ratio improves strength if care is taken to keep the mix workable. However, in the case of the expanded slags, the water/cement ratio had to be kept relatively high (>0.35) in order to have the cement paste coat all the particles and keep the structure together.

4.3 Laboratory Evaluation of SLA for Insulating Concrete

Expanded slag aggregates with a unit weight of 26 lb/ft^3 produced using the fluidized bed expander were screened according to ASTM C 332. In order to evaluate expanded slag for use as an aggregate in insulating concrete, specimens were made for testing of compressive strength and thermal properties. Using the mix proportions for perlite insulating concrete reroofing as a guide, 2" cubes and a 12" x 12" x 1" slab were made using 3/8" x 0 expanded slag according to the following formula:

Type I cement:	800 g
3/8" x 0 expanded slag:	4 times cement by volume
Water:	640 g
Air-entraining agent:	8.3 g
10 mm polypropylene fibers:	8 g

These samples were mixed according to ASTM C 109 and cured in a 98% relative humidity chamber set at 25°C. After 7 days, the cubes were removed for testing of their compressive strength. The highest 7-day compressive strength achieved was 1750 psi, and the unit weight of the samples was approximately 51 lb/ft^3, which is lower than expected values.

4.4 Laboratory Evaluation of SLA Products for Loose Fill Insulation Application

Expanded slag produced using the fluidized bed expander was screened according to ASTM C 549 for use as loose fill insulation. The SLA was then shipped to a commercial laboratory to test for thermal properties.

4.5 Conclusions and Recommendations

Based on laboratory-scale tests conducted for various applications, the following preliminary conclusions can be drawn:

- The 7-day compressive strength of the roof tile concrete specimen at 2800 psi was close to the value obtained for the control specimen (3390 psi) especially when adjusted for the lower unit weight of 93.3 lb/ft^3 of the SLA compared to 105 lb/ft^3 for the control. However, these strengths are both lower than expected values. Tests have been repeated to obtain 28-day values. Methods for improving compressive strength are being investigated.

- The 7-day and 28-day compressive strengths for the insulating concrete specimen were 175 psi and 230 psi respectively at a unit weight of 51 lb/ft^3. The specimens are being tested for their insulating property.

5.0 PLAN FOR THE NEXT QUARTER

The following activities are planned for the next quarter:

- Continue laboratory evaluation of expanded slag products
- Evaluate laboratory applications data to select mix designs for commercial testing
- Plan applications testing at the commercial scale.